Reliable Detection of Bone Alterations: Developing a Reproducible CT Texture Analysis Pipeline

Muhammad Faisal Ahmed, **BMSc**[1], **Jennifer S. Polus** BESc[1], **Brent A. Lanting**, MD, MSc, FRCSC[1], **Matthew G. Teeter**, PhD[1]
[1]Department of Medical Biophysics, Schulich School of Medicine & Dentistry, Western University, London, ON, Canada

Background

- Texture analysis is a non-invasive method that can detect subtle changes in bone and joint tissue that may not be noticeable from the naked eye [1].
- Total hip arthroplasty (THA) can be subject to aseptic loosening, which is difficult to diagnose on regular x-rays.
- Assessing texture features of bone surrounding implants may be used to detect loosening, however metal implants may cause artifacts in CT scans.
- Common workflows for texture analysis broadly include the following steps: image acquisition, image segmentation, feature extraction, and data analysis [2].
- Computation of gray-level co-occurrence matrices (GLCM) based on an image's gray-level values commonly used for feature extraction to assess spatial relationship between pixel pairs [3].
- Currently, there are limited findings of texture analysis in the realm of orthopaedic research, specifically its repeatability with implants.

Study Objective

Develop a robust and reproducible pipeline for texture analysis of CT scans to detect microarchitectural changes in bone structure near orthopaedic implants

Methods

Image Acquisition / Segmentation

1. 5 CT scans of the acetabulofemoral joint obtained from a cadaver using a clinical dose of radiation with and without single energy metal artifact reduction (SEMAR)
2. 3D Slicer used to conduct semi-automatic segmentation to obtain 2 regions of interest (ROI): the femur and acetabulum.
    1. Manual placement of segments on every 3rd slice, followed by filling segments between slices. Threshold approach used to distinguish between bone and surrounding tissue.

Feature Extraction

1. Texture analysis pipeline implemented in MATLAB:
    1. DICOM files for CT scan read and stored into a variable
    2. Image preprocessed using denoising (Gaussian smoothing)
    3. NRRD Binary label-map files for each ROI imported, read, and converted to a logical array
    4. Array used to apply label-map as a mask on pre-processed volume
    5. Gray levels from masked volume extracted and normalized
    6. Gray-level Co-occurrence Matrix (GLCM) computed from gray levels alongside 4 texture parameters: contrast, energy, homogeneity, correlation.

Data Analysis

- Two-tailed, two-sample equal variance t-tests conducted to compare texture parameters between SEMAR and non-SEMAR conditions for CT scans of the femur and acetabulum.

Results

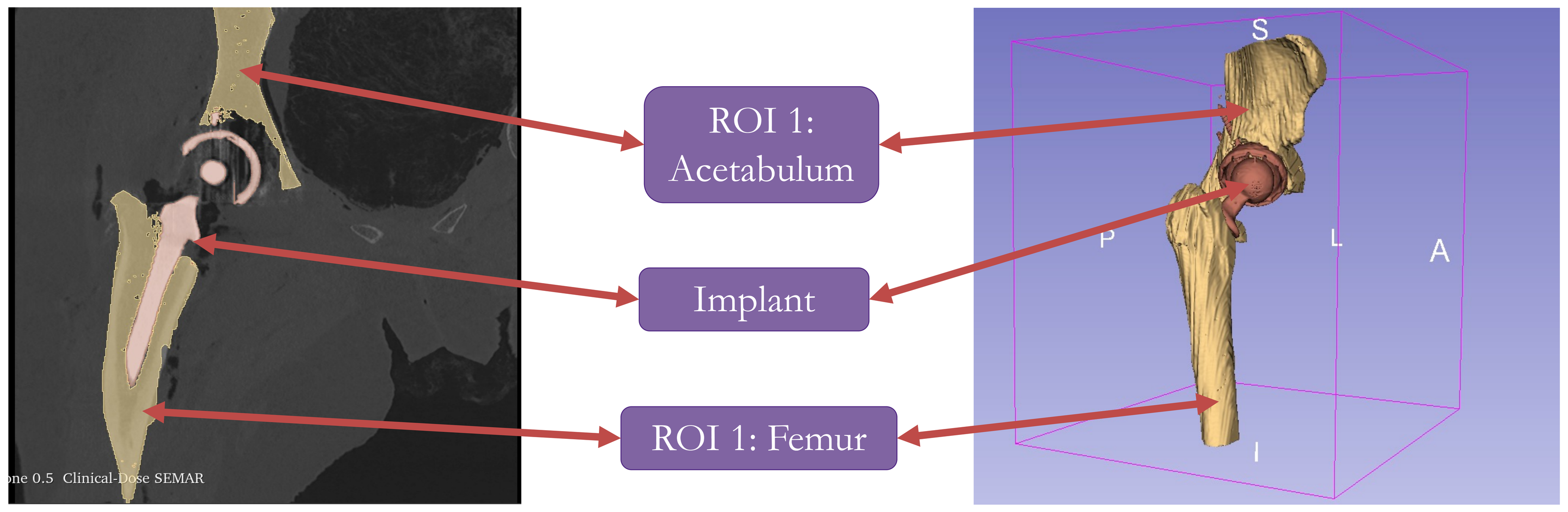

Figure 1. Regions of interest (ROI) placed on CT scan of acetabulofemoral joint and associated 3D model

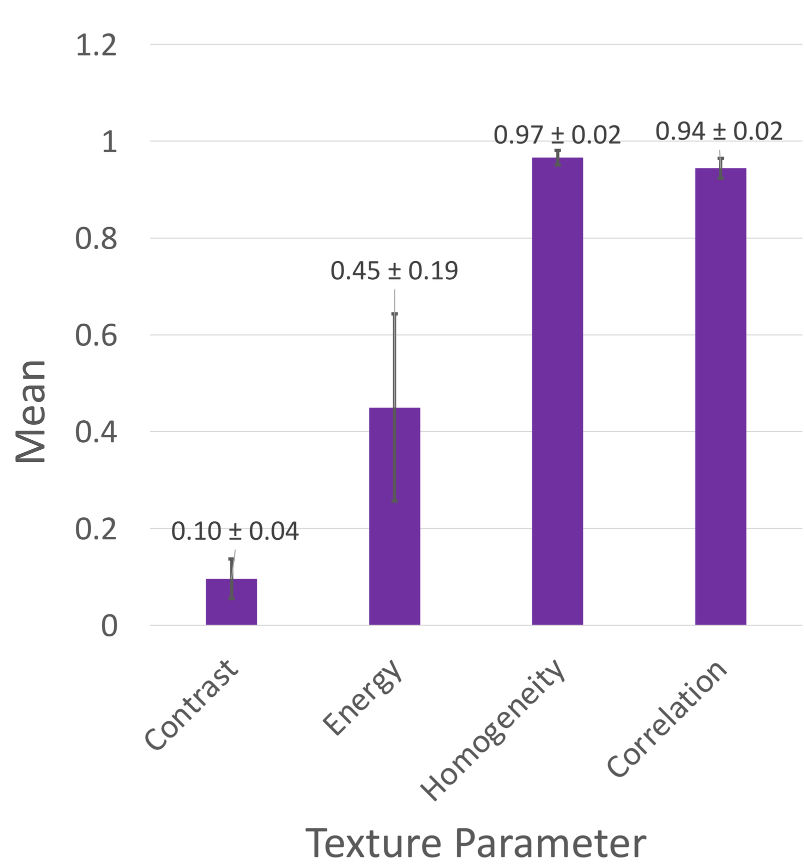

Figure 2a. Texture Parameters of Clinical Dose CT of Acetabulum

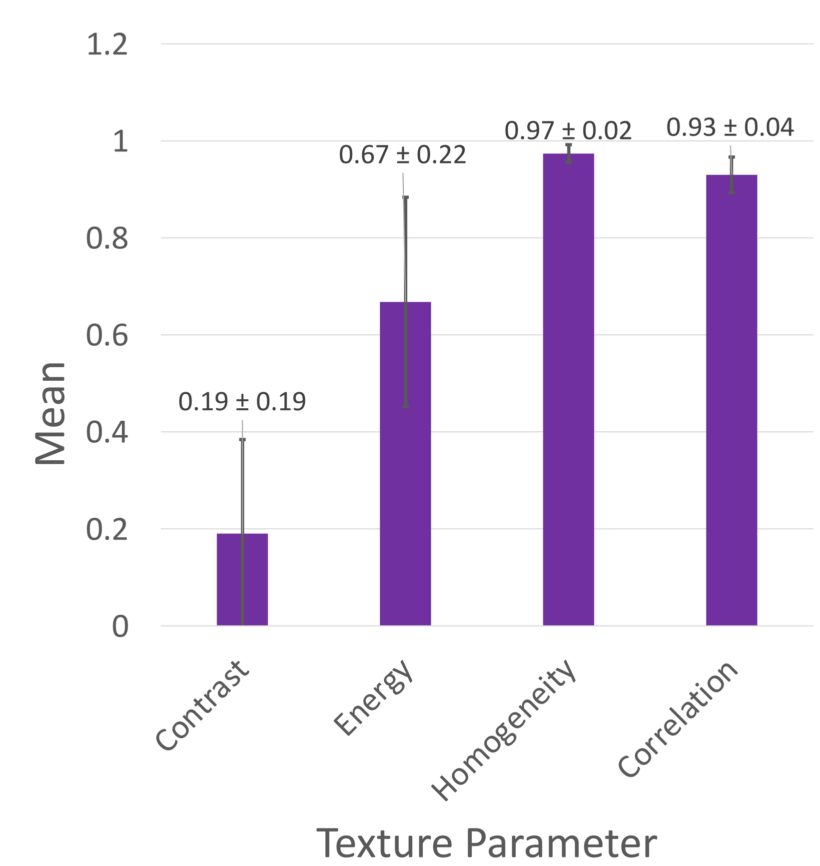

Figure 2b. Texture Parameters of Clinical Dose CT of Femur

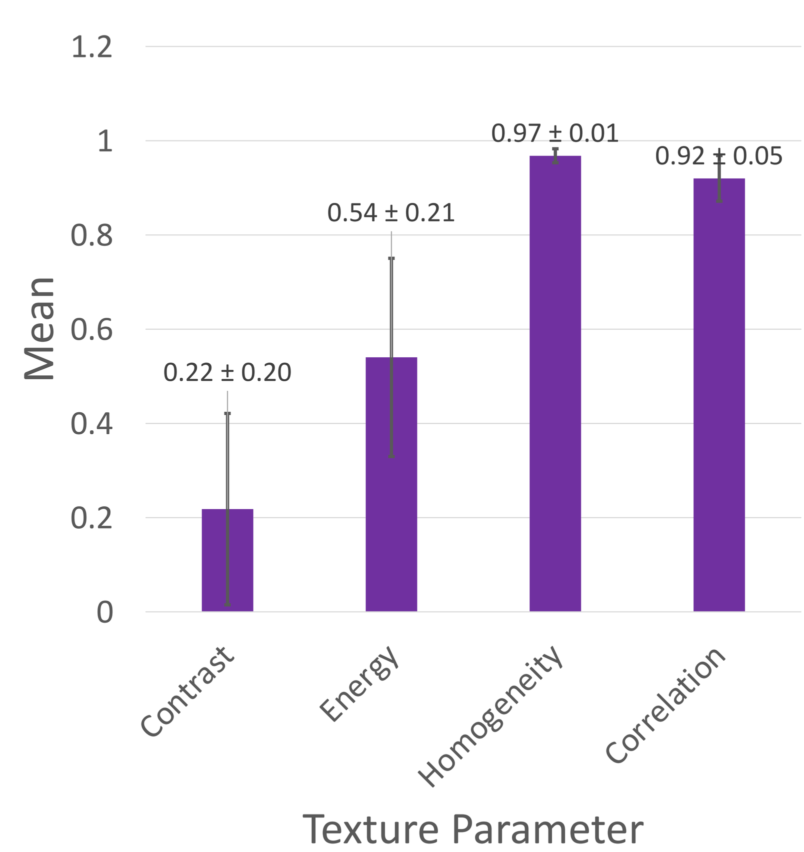

Figure 3a. Texture Parameters of Clinical Dose CT – SEMAR of Acetabulum

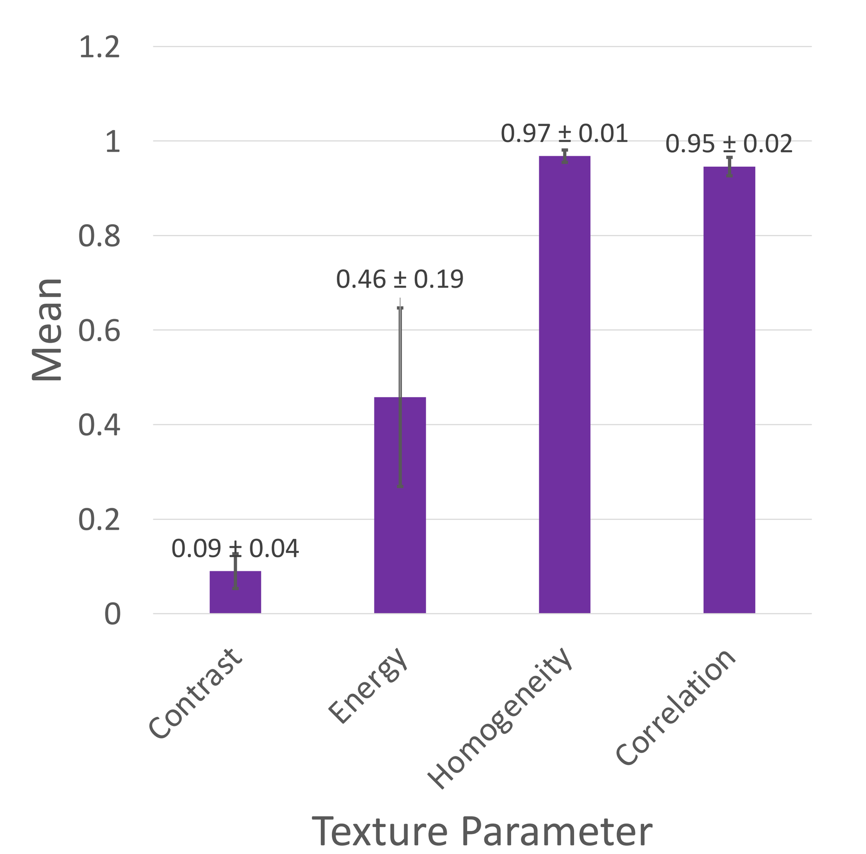

Figure 3b. Texture Parameters of Clinical Dose CT – SEMAR of Femur

- The t-tests conducted to compare texture parameters between SEMAR and non-SEMAR conditions for CT scans of the femur and acetabulum did not yield statistically significant differences ($p > 0.05$).

Discussion

- Relatively higher values of homogeneity and correlation compared to contrast and energy indicate homogenous bone with little changes in the microarchitecture.
- Lack of statistically significant difference between texture parameters of SEMAR and non-SEMAR conditions reflect robustness of pipeline to capture texture features.
- Less variance in values for homogeneity and correlation reflect higher reproducibility relative to contrast and energy.
- Limitations include the limited sample size. Data was obtained from a single cadaver, limiting the generalizability. Segmentation process may include areas beyond those close to the implant which can affect the parameters obtained. Further, the texture analysis package in MATLAB is limited in its computations.
- Future studies should further refine the pipeline to fine-tune its reproducibility as well as the segmentation process in order to obtain ROIs closer to the implant to better assess artifacts.
- Additionally, CT scans from living patients as well as cadavers containing other implant materials should be used to have a better understanding of the texture changes that occur.
- In the future, it will also be important to expand the findings to include other parameters and other feature extraction methods.

Conclusions

- The pipeline created is able to reliably extract texture feature parameters from CT scans of bones with relatively little variance. Relatively higher values of homogeneity and correlation compared to contrast and energy suggest a predominantly homogenous bone structure with minimal changes. Next steps for this study will be to expand the data set to include CT scans from living patients as well as scans of other implant materials/dimensions to assess potential variability in artifacts.

References

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mahme342@uwo.ca @TeeterLab teeterlab.com